Sediment Redistribution and Seabed Modification in the Western Adriatic

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LONG-TERM GOALS

By improving numerical representations of coastal circulation, sediment properties, and wave fields, this project seeks to develop reliable predictions of sediment transport and deposition. Calculations made over seasonal timescales can be validated with available observations. The model can then be used to extrapolate to larger temporal and spatial scales.

OBJECTIVES

Sediment delivery, flux, and deposition are quantified within a three-dimensional hydrodynamic model, linking sediment transport in the western Adriatic Sea to sedimentation. Depositional patterns resulting from point and line sources of sediment are compared by contrasting delivery by the Po River and smaller rivers that drain the Apennine Mountains from north of Ancona to the Gargano Peninsula (see figure 1). Textural and sedimentation patterns will be tested against field observations, and used to synthesize measurements made during the Po and Apennine Sediment Transport and Accumulation (PASTA) experiment.

APPROACH

Detailed forcing is needed to predict dispersal in an area with complex circulation and wind fields, such as the Adriatic. We use a series of linked models as a platform for quantifying sediment transport in the coastal ocean. A model of suspended sediment transport and bed reworking has been built within the Navy Coastal Ocean Model (NCOM, see Martin, 2000). The hybrid sigma / z coordinate system used by NCOM is useful in the Adriatic because the sigma grid is needed within shallow shelf waters, but a z-grid is preferred in deep ocean basins. Winds are specified using predictions from two atmospheric models: the 4km-resolution Naval Research Laboratories COAMPS™ model (Coupled Ocean Atmospheric Mesoscale Prediction System; see Hodur, 1997; Hodur, *et al.,* 2001); and the 6km predictions of the Bologna Limited Area Model (BoLAM; see http://www.cmirl.ge.infn.it/MAP/BOLAM/Bolamin.htm).

The fully three-dimensional sediment transport routines developed for NCOM allow sediment input from fluvial sources and exchange between suspended and sea-floor sediment. Sediment is transported by advection due to settling, oceanographic currents, and turbulent diffusion. The bottom boundary condition of the transport model is the net difference of settling from the bottom-most grid cell, and entrainment from the bed. Multiple grain types are used to track changes to seabed texture, and

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14. ABSTRACT
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15. SUBJECT TERMS

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differential transport of material. The sediment bed model uses a three-dimensional grid underneath the hydrodynamic grid. Sediment within each class is exchanged between the bed model and the overlying water column through erosion and deposition, with the bed model tracking changes to seabed composition. The bed model incorporates bed consolidation and bed armoring.

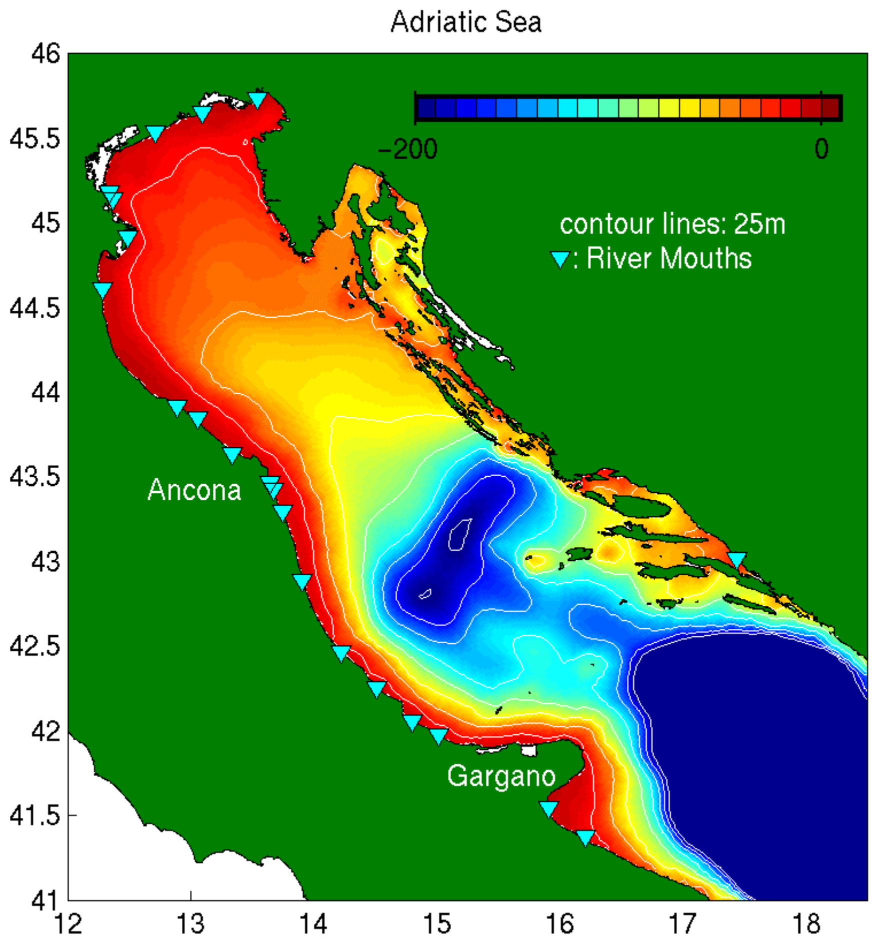

Figure 1: The Adriatic Sea, showing bathymetry, the location of rivers represented within model calculations, and the locations of Ancona and the Gargano Peninsula.

Input fields for freshwater and sediment are difficult to prescribe. Within the study area only the Po, Pescara, and Biferno rivers are gauged. While previous studies provide some guidance for freshwater input (see Raicich, 1994, 1996), and erosion potential (see Aquater, 1982), these provide monthly averages at best. An alternative is to rely on model estimates of freshwater discharge and sediment delivery provided by J. Syvitski and A. Kettner (INSTAAR).

NCOM must be enhanced to include surface gravity waves, a key component for sediment transport and coastal oceanography. Waves increase bed shear stress and apparent roughness in coastal areas, and often dominate transport there (see, e.g. Grant and Madsen, 1979; Smith, 1977, and Drake and Cacchione, 1985). Including waves within NCOM requires generation of a realistic wave field, input routines for wave characteristics, and inclusion of wave/current interaction in hydrodynamic and sediment transport calculations.

WORK COMPLETED

During 2002 and 2003, we improved our representation of the coastal Adriatic in several ways. We worked with Rich Signell (SACLANT-CEN) to revise the model grid based on updated bathymetric data (see Corregiari, *et al.* 1996). This allowed the model to include shallow areas (up to 5m depth), so that the calculations overlap with PASTA measurements. Wave-current interaction modules were incorporated, including a friction factor (Fredsoe, 1993), Grant and Madsen (1979), and Styles and Glenn (2000). The wave field will be computed by Chris Sherwood (USGS) using the SWAN (Simulating WAves Nearshore) model (see Booij, *et al.,* 1999). Current efforts are aimed at using SWAN estimates of near-bed orbital velocity and wave period as input to the wave/current interaction module (see Harris, *et al.* 2003B). To date, however, a steady and uniform wave component has been included, and wave-current shear stresses are estimated following a simple friction factor (Fredsoe, 1993). Simulations have concentrated on two time periods; January 2001 included intense winds and high discharge, and forcing files were available from Pullen, *et al.* (2003). Recent efforts have been aimed at simulating sediment transport during November and December, 2002, a time period that contains floods, high winds, and overlaps with PASTA measurements.

Lacking in previous implementations of the model was adequate treatment of the sediment bed. The study site contains a range of sediment bed types, from freshly deposited muds offshore of the Po River Delta, to fine silts and sands fringing the Apennine margin. Both cohesive and noncohesive sediment beds can limit erosion; sandy beds develop armoring layers, and muddy beds consolidate. These are usually enough to limit sediment suspension in coastal oceans (Harris and Wiberg, 2002). We are developing a model of the sediment bed that accounts for both cohesive and non-cohesive sediment types, including bed armoring of cohesive sediments, as well as consolidation of muddy beds. Formulations were tested by using an idealized setting that represents a 10 X 50 km lake, with water depths ranging from 2m to 18m.

We have updated NCOM input files to include the best data available for each fluvial source of freshwater and sediment, but comparisons between predicted sediment dispersal and PASTA field observations must acknowledge the inherent discrepancy between predictions based on climatological averages and observations made during a particular field season. This year we added 23 rivers to the model, estimating freshwater discharge following Raichich (1994, 1996), and sediment discharge following guidance from Hydrotrend simulations (Syvitski, *et al*. 1998). Discharge of the Po, Pescara, and Biferno Rivers are specified using daily averaged values from the Italian Hydrographic Office. Sediment delivery by all but the Po Rivers was estimated assuming a rating curve based on Hydrotrend simulations (see Syvitski, *et al.* 1998) provided by J. Syvitski and A. Kettner (INSTAAR). These estimates, averaging 145 mg/L are lower than those provided by Aquater (1982) as “erosion potential”, but seem reasonable. Estimating sediment discharge for the Po is also problematic, and will continue to be a challenge for PASTA researchers. Nelson (1970) provides some guidance for concentrations during floods, and Hydrotrend simulations for Po River delivery are forthcoming (J. Syvitski, pers. comm.). At present, the values provided by Nelson (1970) are slated for use in the model. These changes to the input files result in both better resolution of the Western Adriatic Coastal Current (WACC), and improved ability to estimate sediment budgets for the 2002/2003 season.

RESULTS

Results completed using river and wind forcing from January, 2001 imply that dispersal of fluvially delivered sediment depends to the first order on sediment settling characteristics, and secondarily to

wave energy and circulation patterns (Harris, *et al.* 2003A). The direction of dispersal is dependent on wind- and buoyancy driven currents and dominated by transport within the WACC during strong Bora winds (figure 2).

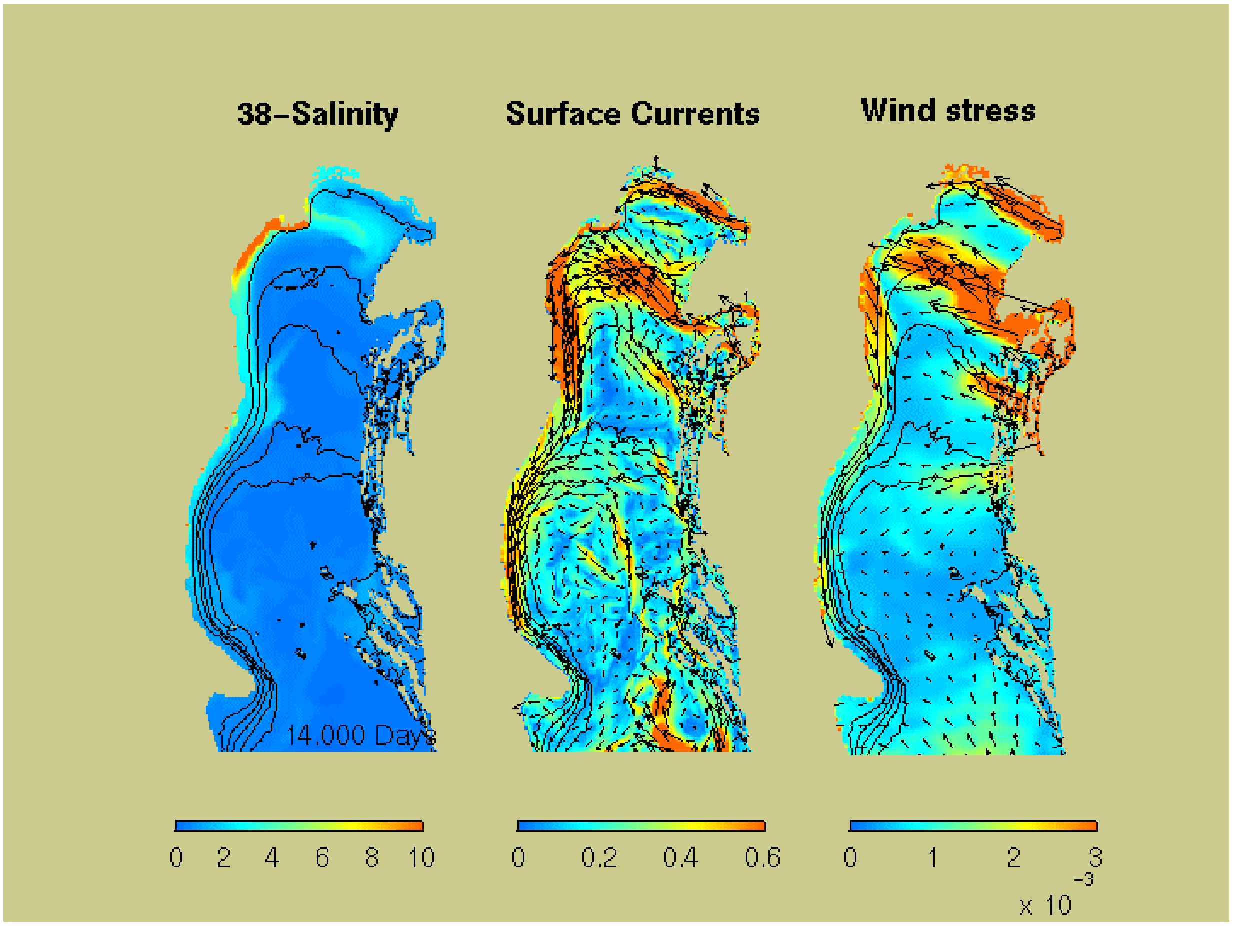

Figure 2: Salinity and currents driven by wind stress and buoyancy output from the Po and Apennine Rivers. Calculations represent January 14, 2001, a time of intense Bora winds, and strong coastal current in the Western Adriatic. Salinity (left panel) plotted as buoyancy anomaly (in ppt). Surface currents represented by magnitude in m/s, ranging from 0 to 0.6 m/s, and direction (arrows). Wind stress from 4km COAMPS™ model represented as magnitudes from 0 to 0.3 Pa; with directions shown as arrows.

Two classes of sediment were input at a constant concentration of 50 mg/L each. One sediment class was modeled as flocculated material (w_s = 1.0 mm/s); and the second as unflocculated material (w_s = 0.1 mm/s). Sediment that is packaged as flocculated material is predicted to settle out of the flood plume of the Po River rapidly, within 10 km of the river mouth (figure 3). Sediment is more widely dispersed if it is delivered as slowly settling, unflocculated particles. Sediment modeled as unflocculated material was transported by the southward flowing coastal current (figure 3). The addition of a depth-varying shear stress from energetic waves (H_{sig}=2m) significantly increased dispersal of both unflocculated and flocculated material, with the flocculated material being confined to the shallowest sites near the coastline. Sediment dispersal is maximized under conditions of strong winds from the northeast, termed “Bora” winds, which intensify the WACC and create merges the

discharge of individual Apennine Rivers into a line source of suspended sediment. Southeasterly Sirocco winds tend to be upwelling favorable, and weaken currents in the western Adriatic, thereby reducing sediment flux. Later simulations that use forcing from November, 2002, show similar patterns and will prove useful for comparing to field observations of sediment flux, which is work in progress for Harris, *et al.* (2003B).

These calculations neglect the addition of material originating from the seabed, which was seen to be a major contribution to the sediment transport field by PASTA (C. Sherwood, USGS, pers. comm.). To represent resuspended material within the diverse sedimentary environment of the northwestern Adriatic we are implementing a seabed model (Harris *et al.* 2004B, in prep.). The Harris and Wiberg (2001) formulation limits erosion of each sediment class during any timestep by the amount of that sediment type in the active layer of the bed. The Sanford and Maa (2001) formulation assumes that entrainment of the bed is limited by the cohesive properties of the bed with depth. Simulations to date, run on a generic lake test case, show that a consistent model can be formulated to represent both cohesive and non-cohesive beds. To do this requires that the seabed model include information about the grain-size makeup of the sediment bed, the porosity and bulk density of the bed, and the depositional history of the bed. Each of these can be stored and updated for a finite number of sediment bed layers.

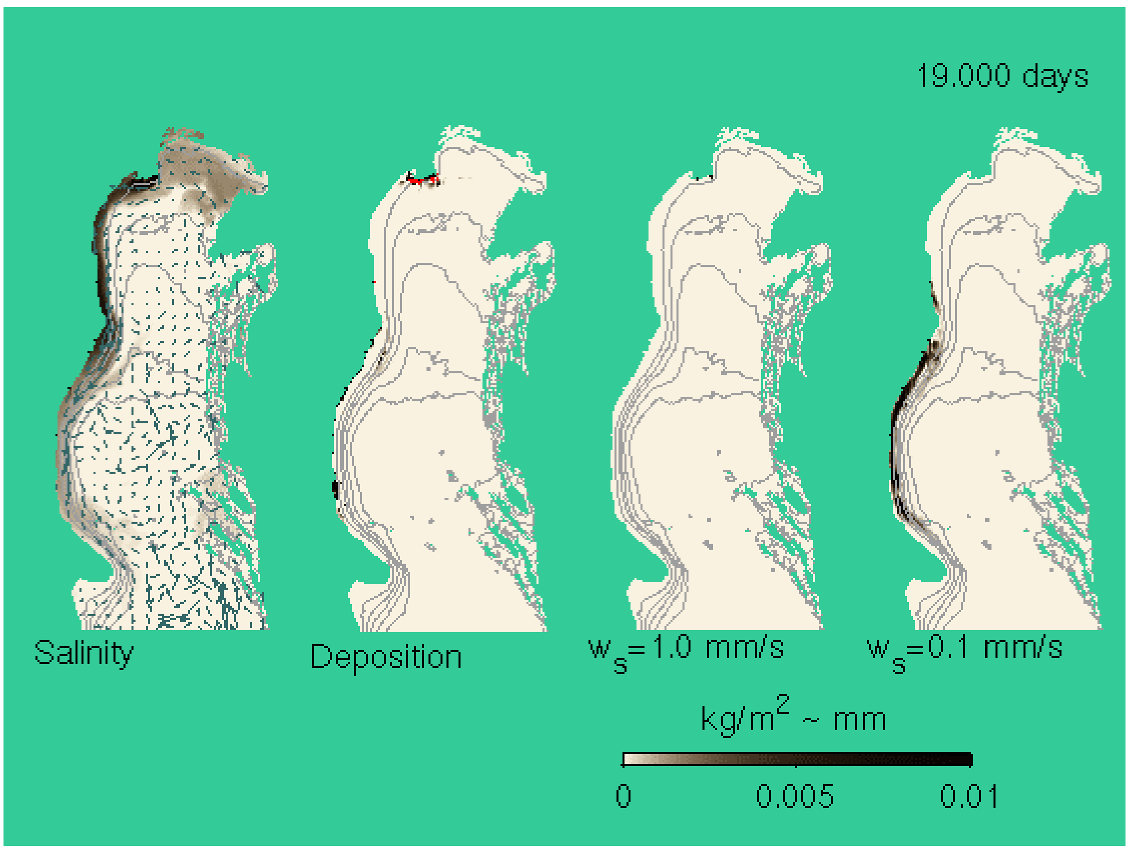

Figure 3: Predictions of sediment dispersal for January 19, 2001. Salinity and surface currents (panel 1) show the tendency of buoyant plumes to hug the coast. Deposition (panel 2) is confined to the Po River delta and Apennine coastline. None of the flocculated material from the Po River remains in suspension (panel 3). Unflocculated material from the Apennine Mountains is dispersed long distances (panel 4).

IMPACT/APPLICATIONS

The development of wave / current interaction and sediment transport routines increases the ability of NCOM to predict circulation, sediment transport, and light attenuation in the coastal ocean. Addition of a wave-current interaction module in particular improves the validity of NCOM in shallow areas, where waves increase shear stress and bottom roughness.

Several components of this work are of interest to EuroStrataform colleagues. The gridded bathymetry, for example, has been supplied to several other P.I.s. Improved estimates of sediment and freshwater delivery during the 2002 / 2003 fall and winter season will better constrain our estimates of sediment budgets during this time.

The sediment bed model described represents an important advance; incorporating a sediment bed model that includes limits to suspension from both bed armoring of a lag layer, and sediment consolidation. Where possible, this has been written as a module, so that it can be ported to other three-dimensional models.

RELATED PROJECTS

Work is underway to publish findings of the STRATAFORM project. I have contributed text towards three of the Master Volume Chapters. Additionally, manuscripts are in preparation that describe the model used to represent both suspended and near-bed gravitational flow, and that quantify the relative contributions of both mechanisms on the Eel Shelf.

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